Activation Analyses with High-energy-charged Particles; Excitation Function of the Reaction 160(3He,p)18F

V. 37 Activation Analyses with High-energy-charged Particles; Excitation Function of the Reaction $^{16}O(^{3}He,p)^{18}F$

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Activation analysis with charged particles is one of the most sensitive methods for determing concentration of trace light elements in metals and semiconductors. Characteristic of these materials seriously dependends on the content of trace light elements. Impurity elements are generally not uniformly distributed in a matrix, whereas usual methods[1-3] of charged-particle-activation analysis can be applied only to uniformly distributed impurities. Among various kinds of impurity, analysis of oxygen content is of special interest in material science, and for this purpose, the reactions $^{16}O(^{3}He,p)^{18}F$ and $^{16}O(t,n)^{18}F$ are expected to be useful. Though the latter reaction has no interference with other reactions[4], the acceleration of tritons is usually troublesome because of the radioactivity. By using the activation analysis based on the reaction $^{16}O(^{3}He,p)^{18}F$, a method of measuring a distribution function of oxygen impurity in a matrix is discussed in this paper, and as the basis for carrying out this method, the excitation function for this reaction has been measured over the bombarding energy range of 10-65 MeV and is reported.

In a case of charged-particle activation, the total radioactivity A_a of a nuclide a produced in a sample is expressed by

$$A_a(R(E_i)) = N_p \rho_s \int_0^{R(E_i)} P_a^i(X)\sigma_a(X)dX, \quad \cdots\cdots\cdots (1)$$

where N_p and E_i(MeV) are, respectively, the number and energy of the incident particle, ρ_s(g/cm^3) is density of the sample S, $P_a(X)$(g/g) is concentration of an element a in S, $\sigma_a(X)$(cm^2) is the nuclear-reaction cross section, $R(E_i)$(g/cm^2) is the range of the incident particle in S, and X(cm) denotes the distance from the surface of the sample.

In a case where an element to be detected is uniformly distributed in the sample, namely $\rho_a(X)$ = constant, an accurate formula for quantitative analysis has been given by the average-stopping-power method.[3,5,6] In a case of nonuniform distribution, however, P(X) can not directly be obtained from the measured activity A_a, but can be obtained from $dA_a/dX \equiv A_a$.

From Fig. (1), A_a is given by

$$A_a'(R(Ei)-X) = N_p \rho_0 P(X)\sigma(X)$$

$$= \frac{A_a(X) - A_a(X-\Delta X)}{\Delta X}, \quad \cdots\cdots\cdots\cdots\cdots (2)$$

Where A'_a are obtained from measurements in connection with chemical etching, and Δx is the thickness of etching. The error of A'_a coming from Eq.(2) is estimated by

$$\left|\frac{\Delta A'_a}{A_a}\right| = \left(\left|\frac{dP/dX}{P}\right| + \left|\frac{d\sigma/dX}{\sigma}\right|\right) \Delta X. \quad \text{.....(3)}$$

If both $P(X)$ and $\sigma(X)$ strongly depend on X, it can not be expected to obtain $P(X)$ with high precision. The first term of the right side of Eq.(3) is considered to be essential and can be reduced by a precise measurement of $A_a(X)$. The second term of Eq.(3) depends on the accuracy of excitation function $\sigma(X)$ of the nuclear reaction. If $\sigma(X)$ monotonously increases or decreases with increase in X, then $\left|\frac{d\sigma/dX}{\sigma}\right|\Delta X$ becomes small. The monotonous change of $\sigma(X)$ is therefore desirable to obtain an accurate measurement of $P(X)$. In general, $\sigma(E)$ rapidly increases from the threshold energy of the reaction, and after reaching a maximum, it slowly decreases.[7] Accordingly, high-energy bombardments are preferable for the activation analysis of a light element which is concentrated in the surface region of a sample.

The cross section $\sigma(E)$ for the reaction $^{16}O(^3He,p)^{18}F$ rapidly increases up to $E_{^3He}$ = 8 MeV and after then[8,9] it decreases approximately in proportion to $1/E^2$. The measurement has been reported over the energy range $E_{^3He}$ = 0 - 30 MeV, and the result obtained by Brill et al.[9] shows very slow decrease in the region near 30 MeV, and suggests that the term $\left|\frac{d\sigma(X)/dX}{\sigma}\right|\Delta x$ would be very small-preferably negligible-in this energy region. Thus we have tried to extend the measurement of the excitation function up to $E_{^3He}$ = 65 MeV.

The experiment was done by stack-foil method. A stack of twenty thin-glass films, each of which is ~10-mg/cm^2 thick, was bombarded with 65-MeV-^{3}He beams, and the induced radioactivity was measured by detecting 511-keV γ rays coming from the positron decay of ^{18}F. (The reactions $^{16}O(^3He,p)^{18}F$ and $^{16}O(^3He,n)^{18}Ne$ contribute to the ^{18}F production, but the latter contribution is very small.[9]) The excitation curve has thus been obtained with energy steps of $\Delta E_{^3He}$ = 200 keV and is shown in Fig. 1. It is seen in this figure that $\sigma(E)$ has a plateau in the energy region $E_{^3He}$ = 50 ~ 65 MeV. The activation method using this bombarding energy region therefore makes it possible to measure precisely the distribution function of oxygen in a sample. Taking a silicon crystal for instance, the depth from the surface measurable with this method is 0.18 g/cm^2 (= R(E=65 MeV) - R(E=50 MeV)). By comparing with a standard sample of silicon oxide, the distribution function $P_{Si}(X)$ of oxygen in the silicon crystal is given by

$$P_{Si}(X) = \frac{N_\rho^{SiO_2}\ \rho_{SiO_2}\ P_{SiO_2}(R(Ei)-R(E_0))}{N_p^{Si}\ \rho_{Si}} \frac{A'^{Si}(R_{Si}(Ei)-X)}{A^{SiO_2}\ (R_{SiO_2}(Ei)-R_{SiO_2}(E_0))}$$

$$\text{.....(4)}$$

where E_i and E_0 are 65 and 50 MeV, respectively. It is assumed in Eq.(4) that oxygen is concentrated in the region $R_{Si}(E_i) - R_{Si}(E_0)$ and thickness of the standard sample is $R_{SiO_2}(Ei) - R_{SiO_2}(E_0)$.

In the present method, thickness of the sample after etching must precisely be measured, and etching and the measurement of radioactivity must alternatively done several times. An arrangement for making automatically these processes is now under construction in our laboratory.

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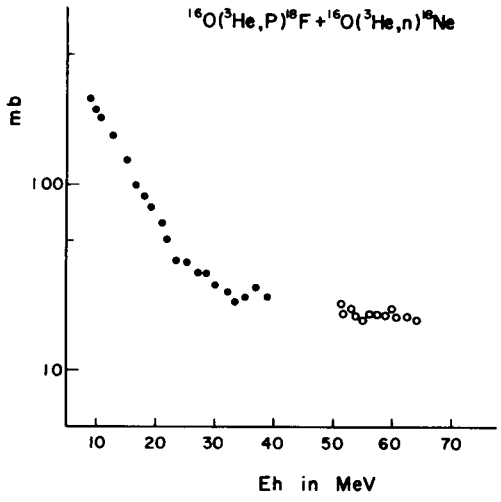

Fig. 1. Combined cross sections for ^{18}F production in $^{16}O(^3He,p)$ and ^{18}Ne production in $^{16}O(^3He,n)$. The cross sections (o) in the energy region 50–65 MeV are shown in arbitrary units.